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ABSORPTION AND PENETRATION OF PRESERVATIVES APPLIED TO SOUTHERN PINE WOOD BY DIPS OR SHORT-PERIOD SOAKS

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It is generally conceded that preservatives applied to wood by dipping or short-period soaks usually afford only surface protection. Non-decay-resistant woods given such treatments last but slightly longer than untreated wood in severe soil burial tests (1).[1] On the other hand, dip- and soak-treated wood has lasted surprisingly long in above-ground exposure where the decay hazard is created by rain seepage into joints (28). A 3-minute dip in a water-repellent preservative is a standard treatment for window sash, and although accurate service records are not available the general impression is that the treatment has markedly reduced stain and decay.

During the past 15 years, the Southern Forest Experiment Station has been conducting extensive field exposure tests on the effectiveness of brush, dip, and short-period soaks in protecting wood exposed off the ground but subject to rain seepage at joints (28). In conjunction with these tests, numerous observations and measurements were made on absorptions and penetrations by these simple applications. General statements based on these studies have been made in reports on the service tests (28), but the actual data are here published for the first time. It is hoped that they will be helpful in delimiting the usefulness of dip and soak applications and in preventing undue reliance on treatments whose effectiveness is not commensurate with the decay hazards involved.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 29.

SUMMARY OF RESULTS

With dips and short-period soaks liquids moved into southern pine wood mainly through the wood and ray tracheids. Resin ducts were penetrated for long distances beyond the generally treated wood with no evidence that the solutions spread from the ducts to surrounding tissues. Resin ducts, therefore, played an unimportant role in these tests (page 7).

The absorption and penetration of water and light oils were found to vary with the characteristics and condition of the wood, and with treating conditions:

Wood characteristics.--The ratios of absorptions through radial, tangential, and transverse surfaces were 1/1.7/11.7 and of penetrations in tangential, radial, and longitudinal directions 1/1.6/11.2. Thus penetrations were directly proportional to absorptions (tables 1 and 2, pages 6-8).

There were often significant differences in treatability of samples from different boards or trees. In some cases at least, these appeared to be inherent differences not associated with infections, straightness of grain, or other obvious characteristics (table 6, pages 9, 13).

Sapwood treated much more readily than heartwood from the same board but among boards there was an occasional overlapping between heart and sap samples. Next to the heartwood there appeared to be a layer of sapwood of low permeability. In general, summerwood showed greater penetration than springwood, particularly in fast-grown samples (tables 3 and 4, pages 9-11).

There was an indication that absorptions are inversely proportional to specific gravity, but the relationship was not established statistically (tables 5 and 6, pages 12-13).

Wood condition.--When treated at the same moisture content, kiln-dried wood appeared more permeable to oil and less permeable to water than air-dried wood. Further tests would be necessary to establish such a relationship, however (table 7, pages 13-15).

Both above and below the fiber-saturation point absorptions were inversely proportional to the moisture content of the wood (tables 8 and 9, pages 15-16).

Rough lumber absorbed 1.7 times as much oil as planed samples of the same size (pages 16-17).

Fungus infections markedly affected absorptions and penetrations. The mold *Trichoderma* and a decay fungus increased permeability greatly. This applied to both longitudinal and transverse penetration but, in the case of the mold, the greatest increase was through the tangential surface or in a radial direction. The mold *Penicillium* and stain fungi caused a less marked increase in permeability (tables 10-13, pages 17-21).

Treating conditions.--A high proportion of the total absorption occurred during the first few seconds of immersion. The rate of further absorption decreased rapidly with increased immersion time (table 14, pages 21-24).

The addition of water repellents to an oil solution significantly reduced both absorption and penetration, but this disadvantage must be weighed against the effect of water repellents in turning liquid water and thus reducing decay hazard (30) (table 15, pages 24-25).

Wood given 3- to 10-minute dips in pentachlorophenol alone or with water repellents was resistant to further treatment for several weeks. After 8 months, only wood treated with water repellents was still resistant to retreatment (table 16, pages 24, 26-27).

Ordinary variations in air temperatures in the Gulf States did not appear to affect the viscosity of light oils sufficiently to affect absorptions measurably. However, fluctuations in air temperatures sometimes did affect absorptions, presumably because mild hot-and-cold or cold-and-hot treatments resulted from different heating and cooling rates of wood and oil (pages 26, 28).

Most of the differences found are probably of little practical importance because it is seldom that the associated factors are subject to control. The data indicate that, barring fungus infections, any likely on-the-job application will result in little lateral penetration into the wood. One important factor that is controllable is moisture content of the wood at the time of treatment. Wood should definitely be well below fiber saturation prior to treatment by dip or short-period soak.

MATERIALS AND METHODS

The wood was southern yellow pine of 2 general types:

(1) Commercial kiln-dried lumber was used in about half the tests. The boards were selected for apparent absence of fungus infections, knots, resin pockets, and similar defects. No attempt was made to weed out slightly off-grain boards, except that samples for special tests on radial, tangential, and longitudinal penetrations were selected for trueness of grain. In most cases, wood species could not be determined, but probably all the important southern yellow pine species were represented. The lumber originated in Arkansas, south Mississippi, and central Alabama.

(2) The other samples were prepared from green wood--either freshly sawn lumber secured at mills or cut from freshly felled longleaf pine trees. The green samples were air-dried or kiln-dried and handled so as to exclude or to favor fungus infections as desired. Except for special comparisons, samples were surfaced after seasoning to correspond to commercial practice.

In general, lumber was cut into strips 1 by 1 or 1 by 2 inches in cross section and of sufficient length to furnish 1 sample (3 to 10 inches long) for each test category. Within a strip, samples were randomly distributed among treating categories. When a number of categories were used, the samples for longitudinal and lateral absorptions were cut from adjacent strips. Usually 10 samples were used for each test category.

After seasoning or special handling to suit needs, samples were strip-piled on a laboratory shelf until they attained a uniform moisture content. This varied from 10 to 14 percent depending on season. Except in special tests, therefore, air-dried and kiln-dried samples were treated only after both were at the same moisture contents.

Usually absorptions were restricted to certain surfaces, as end or lateral. Non-test surfaces were coated with an oil- and water-resistant vinyl chloride paint that effectively excluded from test the coated surfaces.

In most tests commercial preparations containing 5 percent pentachlorophenol in mineral spirits were used. Some contained the water repellents being used for the commercial treatment of sash and millwork. Some of the water-repellent solutions were of unknown properties; some met Federal Specification TT-W-572. Both groups gave similar results. A concentrate of copper naphthenate (8 percent Cu) diluted with kerosene was also used.

Dyes, DuPont oil red for oil solutions and aniline blue for water, were added to stain the treated wood for penetration measurements. Absorption rates of dyed and undyed oil solutions were not significantly

different but it can only be assumed that penetration of the dye and preservative were the same. Penetrations were determined after a week or more of open-piled drying of the treated wood. The samples were split and the limits of the dyed wood measured in a longitudinal and radial direction in millimeters. In a few tests tangential measurements were also taken. With water solutions the dye limits were quite sharp and easily measured, but with the oil solutions the dye varied from deep red near the surface through varying shades to the straw color of the wood. Thus measurements of oil penetration were subject to considerable error. The absolute values for penetrations and comparisons among oil tests should be taken with a grain of salt.

For treatment the samples were placed in racks holding the samples apart, and then were immersed in about 3 or 4 inches of solution. Weights to 0.01 gram were taken before and after immersion. Temperature of the treating solution varied slightly between the start and finish of big tests. To equalize this and other treating errors among all categories, the matched samples from 1 or 2 strips were treated at one time except in tests where special factors prevented. After immersion, the samples were quickly wiped with a cloth to remove excess solution before weighing.

EFFECT OF DIFFERENT FACTORS ON ABSORPTION AND PENETRATION

Direction of Grain

It is generally agreed that penetration is greatest longitudinally (2, 17, 23, 25, and others). The capillary structure of normal coniferous wood (23) consists of (a) the transient spaces around the micelles, (b) the combination of tracheid cavities, pit chambers, and pit-membrane pores, and (c) resin ducts and rays. The transient cell-wall capillaries are operative only with water and other liquids that swell wood. Thus they are not important in treatment with petroleum oils. Even with water, the transient cell-wall capillaries probably account for a very small part of the total effective capillary structure (23). In woods without important resin ducts or conducting rays, the ratio of longitudinal to transverse penetration is the ratio of the length to width of the average tracheid lumen (23).

Tangential penetration is greater than radial in most conifers (19). Bordered pits are usually much more prevalent on radial walls, thus facilitating tangential penetration more than radial. Some springwood is more resistant than summerwood (17, 25)--a circumstance that again favors tangential penetration. But pines have well-developed radial resin ducts that are quite permeable (17, 19, 20, 25). Pine and spruce also have well-developed ray tracheids. It is probably for these reasons (i.e. ray ducts and ray tracheids) that the rays of pine and spruce are easily penetrated (25). Radial penetration in pine wood is usually better than tangential penetration (17, 25).

Teesdale (25) found the following ratios of tangential/radial/longitudinal penetration of southern pine heartwood under pressure: Longleaf 1/4/100, shortleaf 1/7/55, and loblolly 1/4/80.

Most of the penetration studies of wood have been by diffusion or pressure-permeability calculations (7, 12, 20, 23, 24). Soaking involves a combination of capillary rise and liquid flow, as does pressure treatment (23). The same general principles ought to apply to both pressure and dip treatments, but rates and differences may not be of the same magnitudes. This probably is particularly true where treating depths are insufficient to create appreciable hydrostatic pressures. Without external pressure there is a buildup of back pressure of air within wood, causing the rate of capillary rise to decline rapidly (23).

When the present tests were made, very little published information was available on the penetration of solutions by dips and soaks. Lindgren (13) found that aqueous solutions applied as 10-second dips penetrated shortleaf pine 1.5 to 3.5 mm transversely and 5 to 10 mm longitudinally. Hubert (10) reported that a 10- to 15-minute dip in a millwork-grade oil-treating solution resulted in 5 inches of longitudinal penetration in sapwood of species that he did not identify. Such penetration is not obtainable in uninfected southern pine. Since the present tests were

completed, Brown et al. (4) have reported carefully conducted tests with ponderosa pine sapwood. The relative rates of penetration and absorption varied somewhat with different preservatives used in mineral spirits, but in general penetrations with a 10-minute soak were: radial 1.5 to 3 times and longitudinal 20 to 30 times tangential in seasoned wood.

The average end and lateral absorptions in all tests are summarized in table 1. In each test the difference was highly significant statistically.

It must be remembered that the data in table 1 are from widely divergent tests, in terms of time, source of wood, specific gravity, seasoning condition, straightness of grain, etc. Hence only the most general conclusions can be drawn. The data indicate that the ratio of end to lateral absorption is roughly 10 or 11 to 1, with an indication that fungus infections reduce the ratio. For the infected material the ratios in 7 of the 9 individual comparisons were less than the matched uninfected wood. The ratios for 5 seconds were lower in all 5 tests than for the matched 3-minute samples. The lower ratio for kiln-dried wood may also be real; at least it held in the 2 matched comparisons as well as the unmatched comparisons in table 1.

The data of the 3 tests in which the dimensional directions were separately considered are summarized in table 2. There was reasonably close agreement in the ratios of absorptions through tangential, radial, and transverse sections and penetrations in radial, tangential, and longitudinal directions. These were respectively: 1/1.7/11.7 and 1/1.6/11.2. Considering that the greatest differences were between the two trials with pentachlorophenol in mineral spirits without a water repellent, the data indicate that at most there are but minor differences in the ratios for water and pentachlorophenol alone or with a water repellent.

Penetration in vertical resin ducts was usually several times as great as in the adjoining wood tracheids. (Resin-duct penetration was ignored in measuring penetration in mm.) The treating solution did not penetrate the parenchymatous border of the resin ducts or enter the tracheids. In a refractory batch of hot-soaked 7-foot pine sapwood posts, lateral and end penetration was negligible except for the resin ducts, which were treated throughout. It is doubted that resin ducts are of much consequence in effective longitudinal penetration of pine sapwood by dip treatment.

The greater absorption in a radial as compared to tangential direction is probably due to the resin ducts in fusiform rays and to the well-developed ray tracheids. Teesdale (25) and Scarth (20) reported that creosote under pressure spread out longitudinally from the radial resin ducts. From the generally better radial penetration in the current tests one assumes that the rays were important. As with the vertical ducts, the ray ducts were penetrated to greater distances than the ray tracheids, but the solution seemed to be confined to the ducts. It seems that the ray tracheids are more effective avenues for radial treatment than are ray resin ducts.

Table 1.--Average absorptions of water and oil solutions through end and lateral surfaces

Immersion period	Wood condition	Comparisons	Amount of solution absorbed per 100 sq. cm		Ratio, E/L
			End	Lateral	
		Number	Grams	Grams	
5 sec.	Uninfected sapwood	5	6.2	0.8	7.8
3 min.	do.	20	13.9	1.3	10.6
10 min.	do.	9	15.0	1.7	8.8
15 min.	do.	2	19.4	1.8	10.8
30 min.	do.	6	18.6	2.0	9.3
60 min.	do.	5	21.1	2.2	9.6
3 min.	Uninfected heartwood	1	6.2	.8	7.8
3 min.	Sapwood				
	Uninfected, kiln-dried	13	13.3	1.4	9.5
	do. , air-dried	7	15.2	1.2	12.7
	Uninfected, oil alone	15	14.4	1.4	10.3
	do. , oil plus water repellent	3	11.5	1.1	10.5
	Uninfected, water	2	14.3	1.4	10.2
	Uninfected, all	20	13.9	1.3	10.6
	Infected, all	9	38.4	4.8	8.0

Table 2.--Relative absorptions and penetrations in tangential, radial, and longitudinal directions in 3-minute dips

Solution	Absorption ratio: rad./tang./end surfaces	Penetration ratio: tang./rad./long. distances
Pentachlorophenol in mineral spirits	1 : 1.8** : 16.7**	1 : 1.3 : 15.6**
Do.	1 : 1.4* : 8.2**	1 : 1.0 : 8.9**
Pentachlorophenol plus water repellent in mineral spirits	1 : 1.6** : 12.5**	1 : 1.4**: 10.3**
Water plus aniline blue	1 : 1.9** : 10.8**	1 : 3.2**: 12.4**
Geometric mean	1 : 1.7 : 11.7	1 : 1.6 : 11.2

1/ * and ** indicate values significantly greater, at the .05 and .01 level, than the value for the radial surface or tangential direction.

Variation among Boards and Trees

Analyses of variance were made of data from seven tests to get information on differences in permeability among trees or boards. In four of these tests, commercially kiln-dried lumber was used. It was not known from how many trees the boards came or even whether all boards in a test were of the same species. In all four cases a significant amount of variance was ascribable to board source. This applied to boards from the same mill as well as from widely separated mills.

For the fifth test samples were taken from six longleaf pine trees which grew in close proximity. Samples from each tree were dipped in pentachlorophenol, pentachlorophenol plus a water repellent, and water. No significant variance due to tree source was found.

Samples for the sixth test were taken from the outer rings at different heights in 3 longleaf pine trees from different stands at the Harrison Experimental Forest. There was a significant difference in permeability among the trees (table 6, page 13) but not at different heights or among samples at a given height.

In most tests, variance due to board or tree source was exceeded only by that due to infected vs. uninfected and end vs. lateral surface.

Radial Position in Sapwood

Scarth (20) found boards of northern pine to differ in permeability across the grain and also vertically along growth rings. Erickson et al. (7) found western hemlock sapwood (2.5 inches thick) from near the heartwood and near the bark to be of equal longitudinal permeability.

Wood from 3 boards of fast-grown, radially sawn southern pine of unknown history was cut into 0.5-inch strips. The samples were taken at distances of 0.5 to 2.5 inches from the heartwood-sapwood boundary and were coated to exclude absorption except on the tangential surfaces farthest from the heartwood. They were dipped for 3 minutes in 5 percent pentachlorophenol without a water repellent. The data are presented in table 3.

There was no well-defined gradient in permeability with radial position in the sapwood. However, near the heartwood there appeared to be a zone of sapwood considerably less permeable. As separation of sapwood from heartwood was done visually, the inference is that permeability change precedes the color change from sapwood to heartwood.

Springwood vs. Summerwood

It is generally accepted that summerwood treats better under pressure than springwood in most species, or at least allows a greater

Table 3.--Effect of distance from heartwood on absorption through the tangential surface in a 3-minute dip

Distance from heartwood (inches)	Absorption, per 100 sq cm				Radial penetration, mm			
	Board 1		Bd. 2	Bd. 3	Board 1		Bd. 2	Bd. 3
	Loc. 1	Loc. 2			Loc. 1	Loc. 2		
	Grams				Millimeters			
0.5	0.4	0.9	0.4	0.6	1	+	1	+
1.0	2.4	2.2	2.5	2.3	4	4	4	5
1.5	2.2	2.6	3.4	3.3	5	4	4	4
2.0	2.5	2.7	3.5	3.7	6	4	4	4
2.5	2.4	2.3	3.5	3.3	5	4	6	5

penetration (see literature review in 7). The springwood of rapidly grown southern pine reportedly is particularly low in penetrability (26). In contrast, pressure-flow studies show that longitudinal flow through spruce sapwood (20) and southern pine sapwood (7) is greater in springwood than summerwood. Apparently quite different and unknown factors operate in the two types of tests. Even though summerwood is more easily penetrated, springwood has a greater void volume and can retain more preservative. Springwood of freshly pressure-treated southern pine sapwood usually contains more solution per unit volume of treated wood than does summerwood (5).

In some of the current tests longitudinal penetrations were measured in springwood and summerwood. In the 3 tests in which separate measurements were taken the penetration in summerwood was usually double that in springwood. This applied to treatment with pentachlorophenol alone or with a water-repellent, and also to treatment with dyed water only. Differences were particularly marked in fast-grown wood but were small or absent in slow-grown even-textured wood. Lateral penetration appeared greatest when summerwood was exposed on the surface of the lumber. In an additional test no difference was found in penetration of summer- and springwood heavily infected with either Trichoderma or Penicillium.

The over-all impression from the current tests is that with southern pine sapwood greatest penetration with a dip treatment usually occurs in the summerwood. Fungus infections can obliterate the difference, however, and little difference may occur between seasonal bands in fine-grained wood (15 or more rings per inch).

Heartwood vs. Sapwood

In most species the heartwood is much more resistant to pressure impregnation (25) than is sapwood. To judge from the results of pressure-flow studies (7), the ratios of penetrability of sapwood and heartwood vary greatly among species. In recent tests with shortleaf pine (2), dips and cold soaks penetrated sapwood further than heartwood. Condition of seasoning and length of immersion influenced the ratio.

Heart- and sapwood samples were cut from edge-grained pine 2- by-4's. The transition zone was avoided but the samples were essentially outer heartwood and inner sapwood. The data are summarized in table 4. In each board the heartwood was less absorbent, both on lateral and end surfaces. In both lateral and end absorptions, however, certain heartwood samples absorbed as much as or more than some unmatched sapwood samples. Apparently, variability within sapwood or heartwood is sufficiently great so that the two categories overlap in permeability rather than having sharp delimitations. Teesdale (25) found that some heartwood samples treated under pressure like sapwood.

Table 4.--Relative absorption of copper naphthenate (0.5 percent Cu) or 5 percent pentachlorophenol in kerosene by kiln-dried southern pine sapwood and heartwood in a 3-minute dip

Rings per inch		Total absorption		Absorption, per 100 sq cm			
				End surfaces		Lateral surfaces	
Sap	Heart	Sap	Heart	Sap	Heart	Sap	Heart
Number		Grams					
5	5	13.0	1.3	...	...	...	...
10	6	3.9	1.9	...	...	...	...
17	5	5.2	2.7	...	...	...	...
10	4	3.5	.4	...	...	...	...
16	1	3.3	2.4	...	...	...	...
15	5	...	...	2.3	0.8	0.20	0.14
4	3	...	...	1.7	.3	.17	.05
6	4	...	...	1.4	.3	.11	.05
6	4	...	...	1.4	.3	.17	.08
12	14	...	...	2.0	1.4	.14	.06
5	5	...	...	1.4	.3	.11	.05
Average		5.8	1.7	1.7	.6	.15	.07

Specific Gravity

General experience with pressure treatments shows no correlation between treatability and specific gravity among different species (7). Within a softwood species low-density samples often are more difficult to penetrate, although density *per se* may not be the determining factor. When pressure-treated to refusal, of course, low-density material usually shows greater retentions. With dips and short-period soaks, absorptions of several oil solutions by ponderosa pine sapwood were found to vary inversely with specific gravity (4). This relationship held for wood treated at different moisture contents. It was also reflected in longitudinal penetration, but differences in lateral penetration were not clearly shown.

In the current tests only a few minor determinations were made of the effect of density on absorption by southern pine sapwood. The relationships found in 3 tests using 3-minute dips in 5 percent pentachlorophenol are summarized in table 5.

In a fourth test samples were taken from the outer 1.5 inch of sapwood of 3 longleaf pines at approximately 0, 10, 20, and 30 feet above ground. This automatically gave a series of specific gravities, because in southern pine density decreases with height in tree (14).

The limited data in table 6 follow, in general, the trends demonstrated for ponderosa pine (4), i.e. an inverse relationship between density and absorption. With none of the data is the relationship statistically significant. It appears that in a general dipping operation other factors may mask the effect of specific gravity. In fact, if low specific gravity is accompanied by wide bands of springwood the sample may have poor treating qualities because of the low penetrability of springwood.

Table 5.--Effect of density of southern pine sapwood on absorptions of 5 percent pentachlorophenol in a light petroleum solvent applied as a 3-minute dip

Test and no. of samples	Specific gravity		Absorption, per 100 sq cm	
	Range	Average	End grain	Lateral grain
			- - - - - Grams	- - - - -
Test 1				
3 samples	0.447 - .507	0.479	11.8	0.95
5 samples	.534 - .655	.571	10.9	.93
Test 2				
4 samples	.323 - .395	.364	15.2	1.40
6 samples	.423 - .473	.442	12.7	1.40
Test 3				
8 samples	.460 - .498	.481	...	1.47
8 samples	.503 - .577	.542	...	2.12

Table 6.--Height of sample blocks in tree, as related to absorption and penetration of 5 percent pentachlorophenol in mineral spirits by longleaf pine sapwood 1/

Tree number	Height in tree	Specific gravity	Rings from pith	Absorption, per 100 sq cm		Penetration	
				End	Lateral	End	Lateral
	Feet			- - - - Grams - - - -		Millimeters	
1	0	0.617	18	8.37	0.84	27.9	2.8
	10	.570	17	9.13	.99	31.4	3.1
	20	.533	12	8.97	.99	29.3	3.1
	30	.512	10	8.79	1.02	29.1	3.5
2	0	.609	18	8.63	.91	27.1	3.6
	10	.530	17	8.08	.65	29.3	2.2
	20	.490	11	8.93	.65	29.6	2.0
	30	.455	9	8.46	.76	30.5	2.5
3	0	.704	18	7.13	.73	23.8	1.9
	10	.677	16	6.87	.70	26.5	2.6
	20	.596	12	7.35	.81	23.0	2.2
	30	.537	9	7.38	.82	24.5	1.7

1/ Each figure is an average of 4 trials.

Air-Dried vs. Kiln-Dried Wood

Kiln-drying pine wood causes resinous extractives to accumulate near the surface (11). This accumulation probably reduces the capillary cross-sectional area. Kilning also tends to increase pit aspiration (8), which would lower permeability. Canadian workers (24) reported that temperatures above 70° C or intense drying of wood causes a permanent increase in permeability. This is the reverse of what one would expect in the light of the investigations referred to above (8, 11). It is conceivable that kilning temperatures, with concomitant uneven drying, open minute checks in the cell walls and that these may act as new capillary passages that more than offset any hindering effects.

In two tests matched air-dried and kiln-dried samples were compared. Kilning was more severe (75° C in a forced-draft oven) than in commercial lumber practice. The data are summarized in table 7.

In general, kiln-drying increased the absorption and penetration of the oil solution. The reverse was true when water was used. Perhaps the resin rearrangements associated with kiln drying had more effect on the capillary attraction of water than oil.

Table 7.--Comparative absorptions and penetrations of water and 5 percent pentachlorophenol in mineral spirits: kiln-dried and air-dried pine sapwood, after 3-minute dips

Treating solution	Average absorption						Average penetration			
	Total		Per 100 sq cm				End		Lateral	
			End		Lateral					
	AD	KD	AD	KD	AD	KD	AD	KD	AD	KD
	- - Grams - -		- - - - - - Grams - - - - - -				- - - - Millimeters - - - -			
Pentachlorophenol	8.5	10.5**	...	...	1.6	2.0**	5.7	17.3**	1.4	1.9*
Do.	...	...	18.6	20.0	1.4	1.6*	53.1	51.3	3.3	4.8*
Water	...	...	16.1*	12.2	1.6*	1.2	11.4 **	6.9	.6	.5

* and ** indicate significantly greater at .05 and .01 level, respectively.

An offshoot of one test had a bearing on the possible effects of resin deposits on absorption and penetration. The end surfaces of freshly felled southern pine ooze oleoresin, which, on drying, forms a pitch encrustation. Four samples with heavily pitched ends were saved. When fully dried one end was sawed off so that each sample had one fresh and one pitched end. The lateral surfaces were coated and the samples immersed in 5 percent pentachlorophenol in a light solvent for 3 minutes. The following penetrations were secured:

Sample	Pitched end	Fresh end
1	Trace	Complete for 7 mm, streaks to 30
2	Spotty, 0-15 mm	Complete for 5 mm, streaks to 20
3	do.	Do.
4	Mostly 0, streaks to 20 mm	Complete for 8 mm, streaks to 40

Wood Moisture Content

Recent studies (4) have shown that absorption and penetration of oil solutions by ponderosa pine sapwood are inversely proportional to the moisture content, both above and below fiber saturation. The moisture contents tested were 0, 12, 25, 35, and 50 percent of the oven-dry weight. The effect of moisture contents below fiber saturation was small on lateral penetration (4, 22).

In two tests in the current series, the same relationships held for southern pine sapwood.

In one test, samples were cut from one sapwood board from each of five longleaf pine trees and kiln-dried at 70° C. Matched groups were conditioned over salt solutions until equilibrium moisture contents of 12, 16, and 25 percent were reached. Half the conditioned samples were end-coated and half side-coated with vinyl chloride.

The samples were dipped for 3 minutes in 5 percent pentachlorophenol plus a water repellent in mineral spirits. The results are given in table 8. All the differences except that between 16 percent and 25 percent for end absorption are significant at the 5-percent level.

In the second test, all samples came from lumber cut from one longleaf pine tree. The lumber was surfaced green and seasoned as follows: (a) immediately kiln-dried at 70° C, (b) dipped in a stain-control solution and partially air seasoned, and (c) treated as in (b) but fully air-dried. When at the desired moisture contents, the samples were made into boxes nominally 3 x 8 x 12 inches (30). A fourth group of samples was treated green. Ten boxes of each moisture group were given a

3-minute dip in 4-percent sodium pentachlorophenate plus 4 percent borax in water and ten in 5 percent pentachlorophenol in mineral spirits. The results are summarized in table 9.

Table 8.--Absorption of 5-percent pentachlorophenol plus a water repellent by pine sapwood at different moisture contents below fiber saturation during a 3-minute dip

Moisture content when treated (percent)	Absorption, per 100 sq cm	
	Through lateral surfaces	Through end surfaces
	- - - - - - - - - - Grams - - - - - - - - - -	
12	0.15	1.72
16	.14	1.59
25	.13	1.54

Table 9.--Effect of moisture content of pine sapwood on absorption of 5 percent pentachlorophenol in mineral spirits and 4 percent sodium pentachlorophenate plus 4 percent borax in water

Type of seasoning	Moisture content	Absorption per box	
		Oil	Water
	Percent	- - - - Grams - - - -	
Unseasoned, green	110	16	31
Partially air-dried	1/ 41	72	67
Fully air-dried	14	106	87
Kiln-dried	9	101	93

1/ With a moisture gradient from outside (30 percent) to inside (65 percent).

Rough vs. Dressed Lumber

In a small laboratory test with sapstain-control chemical solutions, rough samples removed 1.8 times as much solution from the vat as did planed samples (29). Presumably, the roughened surface held more liquid on the surface and part of this later penetrated deeper, thus influencing degree of stain control in rough and planed lumber (29).

In one test, 10 pairs of matched samples from 7 boards were dipped for 3 minutes in 5 percent pentachlorophenol in mineral spirits. Each pair consisted of a rough and planed sample. After being dipped the samples were drained but not wiped before reweighing. The absorptions were:

Rough 2.80 grams per 100 square cm

Planed 1.69 grams per 100 square cm

The difference, 1.11 $\pm$ .161, is highly significant and approximately of the same magnitude (1.7 as compared to 1.8 times) as for the water solutions (29).

Fungus Infections

With the possible exception of stain developing in the living tree, it has been generally accepted that fungus stains increase the permeability of wood to liquids (16 and literature cited therein). Lindgren and Scheffer (16) found that, for water absorptions during a 30-minute immersion, the ratio of stained to unstained pine was 1.2 to 1.7 for different staining fungi. Larger ratios (2.1 to 2.5) resulted from hot and cold bath or pressure treatments with creosote.

There is much less information on the effect of decay on permeability. Scheffer (21) found that sweetgum with 10 percent or more loss in specific gravity induced by *Polyporus versicolor* had a slightly lower fiber saturation point, a greater water absorption rate, and a greater evaporation rate.

Lindgren has recently found (15) that the mold *Trichoderma viride* is particularly effective in increasing permeability to water and oil.

Blew (3) showed that in the cold-soaking process the degree of general fungus infection markedly affects absorption by southern pine posts.

In the current tests five were on the effects of fungus infections. All samples were fresh, green southern pine sapwood treated and seasoned in different ways to secure the desired infections.

Natural infections were secured in three tests by using the following treatments:

(1) Dipped in 2 to 4 percent sodium fluoride to induce heavy growth of *Trichoderma viride* (15, 27).

(2) Dipped in 0.015 percent ethyl mercuric phosphate to induce heavy growth of *Penicillium* (27).

(3) Dipped in a double strength stain-control chemical to prevent all but small amounts of fungus infections.

The treated samples were placed in miniature enclosed seasoning piles (29) and progressively opened to aeration until seasoned. All final preservative treating was done at uniform moisture contents of 12 to 14 percent.

For the fourth test, similar wood was used but the matched green blocks were surface-sterilized in boiling water, placed in sterile glass jars, and inoculated with pure cultures of *Ceratocystis ips*, *Trichoderma viride*, or *Lenzites saepiaria* (representative stain, mold, and decay fungi). Different incubation periods were used to give samples with high and low levels of attack. The blocks were finally air-dried to 14 percent moisture before preservative treatment.

For test five, only *Trichoderma*-molded wood was used. Five-inch long sections from 10 molded fence posts were split in half. One piece from each post was used for absorption by a radial surface, the other by a tangential surface.

Tables 10-13 summarize absorptions and penetrations.

Table 10.--Effects of mold (Trichoderma) and stain on absorption and penetration of 5 percent pentachlorophenol in mineral spirits by pine sapwood during a 3-minute dip (Test 1).

	Molded	Stained	Uninfected
Percent of area stained	Trace	27	Trace
Mold rating (0=none to 5=very heavy)	2.6	3.0	0
Absorption in grams per sample			
Through all surfaces	53.4	32.4	8.5
Through lateral surfaces	50.3	37.6	6.2
Penetration in mm 1/			
Through lateral surfaces	10 +	7 +	1.4
Through end surfaces	110 +	60 +	5.7

1/ + after a figure indicates that some or all samples were completely penetrated.

Table 11.--Effects of mold (Trichoderma) and stain on absorption and penetration of 5 percent pentachlorophenol in mineral spirits and of water by pine sapwood during 3-minute dips (Test 2)

	Molded	Stained	Uninfected
Percent of area stained	Trace	69	Trace
Mold rating (0 to 5)	3.0	0	0
Absorption, grams per 100 sq cm			
Oil--through lateral surfaces	6.2	2.0	1.4
--through end surfaces	44.5	20.9	18.6
Water--through lateral surfaces	4.5	2.0	1.6
--through end surfaces	35.0	19.7	16.3
Penetration in mm 1/			
Oil--through lateral surfaces	12 +	6 +	3.3
--through end surfaces	87 +	52.6	53.5
Water--through lateral surfaces	3.9	.4	.6
--through end surfaces	21.6	8.6	8.0

1/ + indicates that some samples were completely penetrated.

Table 12.--Effect of the molds Trichoderma and Penicillium on absorption and penetration of 5 percent pentachlorophenol in mineral spirits applied as a 3-minute dip and of water applied as a 10-minute soak, by pine sapwood (Test 3)

	Penicillium	Trichoderma	Uninfected
Percent of area stained	0.2	2.6	0
Mold rating (0 to 5)	3.5	4.0	0
Absorptions, grams per 100 sq cm			
Oil--through lateral surfaces	1.9	5.7	1.6
--through end surfaces	28.5	36.7	15.2
Water--through lateral surfaces	3.9	9.1	2.9
--through end surfaces	41.9	66.3	22.3
Penetration in mm 1/			
Oil--through lateral surfaces	4.7	9 +	4.0
--through end surfaces	60 +	60 +	47.1
Water--through lateral surfaces	2.5	4.3	2.3
--through end surfaces	14.7	21.3	9.1

1/ + indicates that some samples were completely penetrated.

Table 13.--Effects of level of infection by stain (Ceratocystis ips), mold (Trichoderma), and decay (Lenzites saepiaria) on the absorption and penetration of 5 percent pentachlorophenol in mineral spirits by pine sapwood during a 3-minute dip (Test 4)

	Stain		Mold		Decay		Uninfected
	Light	Heavy	Light	Heavy	Light	Heavy	
Percent of area stained	35	94	0	0	0	0	0
Mold rating (0 to 5)	Trace	Trace	1.2	2.8	Trace	0	0
Absorption, grams per 100 sq cm							
Through lateral surfaces	2.5	2.6	2.5	4.5	2.5	11.9	1.4
Through end surfaces	35.5	36.0	47.4	85.6	35.0	81.7	23.6
Penetration in mm 1/							
Through lateral surfaces	5 +	10 +	8 +	10 +	9 +	11 +	3.7
Through end surfaces	39 +	39 +	39 +	39 +	39 +	39 +	39 +

1/ + indicates that some samples were completely penetrated (12 mm lateral and 39 mm longitudinal).

All infections increased the absorption rate and, in most cases, the depth of penetration. This applied to both water and oil treatments. The effects of the different types of infection agree well with the known effects of the fungi on wood structure:

Molds.--*Trichoderma viride*, which grows more luxuriantly on pine sapwood than any other common mold, markedly increased permeability. In test 5 the ratio of radial to tangential penetration was 2.8--significantly greater than the average for untreated wood (ratio 1.6) as given in table 2. Apparently the effect of *Trichoderma* on permeability is greater in the radial than the tangential direction. This is probably due to the pronounced breakdown of ray tissue by *Trichoderma* (15), which would facilitate radial more than lateral penetration.

Penicillium induced by mercury treatment grew less luxuriantly than *Trichoderma* and caused no obvious breakdown of ray tissue. It had a less marked effect on permeability.

The increased end absorption associated with mold and stain infections is presumably due to enlargement of the pit-membrane capillaries by the fungi.

Stain.--Except for the inoculated samples, the stain encountered in these tests was caused by *Ceratocystis pilifera*. In general, stain fungi in coniferous woods are more restricted to the rays than are molds and

decay fungi. Stainers do not cause as complete ray breakdown as does *Trichoderma*. The data on absorptions and penetrations of stained wood bear out these contentions. The stained samples, even when deeply penetrated, were not dyed as intensely by the treating solutions as was the *Trichoderma*-molded wood.

In most discussions of the effects of stain on permeability of wood a reservation is made that stain developing in dying trees following beetle attack may not increase permeability. Nelson (18) reported that stain of the type associated with beetle attack in living shortleaf pine trees caused stoppage of water conduction. Furthermore it was found that dyes would not pass through stained zones. During the present studies a few samples were collected from pines freshly killed by beetles. The samples included wood infected with *Ceratocystis ips*, associated with *Ips* beetle attack, and with *C. pini*, associated with *Dendroctonus* beetle attack. All the wood was readily penetrated with oil solutions after air drying. All isolations attempted from stained wood from beetle-killed trees yielded *Trichoderma viride*. Nelson (18) also found this mold commonly associated with beetle attack.

Nelson's data on occlusion were based on wood stained by artificial inoculation and not by beetles. Apparently, the stain occurring in beetle-killed trees is also commonly accompanied by the mold *Trichoderma* and, at least after seasoning, the wood is readily permeable to preservatives.

Decay.--Incipient infections by *Lenzites saepiaria* increased absorption rates in about the same proportion as did stain. However, visible, but not advanced, decay increased absorptions as much as or more than did *Trichoderma*. Decay fungi, in addition to enlarging pit-membrane capillaries, also bore directly through cell walls, thus creating entirely new capillaries. The decay fungus used in these tests makes large holes through cell walls and may have increased permeability more than some other decayers would have. In a practical sense, the big effects of decay beyond the incipient stage are lessened by the slow growth of these fungi. Advanced decay is seldom encountered in wood being treated, except for localized pockets.

Length of Immersion

In pressure-treating, the rates of penetration and absorption decrease parabolically with time (9). With cold soaking treatments in which no artificial external pressure and little hydrostatic pressure are operative, the build-up of back pressure should be particularly effective in decreasing the rate of absorption with length of immersion. Initial absorptions with dip and cold soak treatments of dry wood are high (4, 6), probably because of the initial unrestricted capillary action (23). After this initial spurt the rate of absorption falls off rapidly with increased immersion time.

In the current tests, the relationship of absorption and length of immersion was determined for lateral and longitudinal penetration in 6 tests using kiln-dried southern pine sapwood. The data are summarized in table 14.

When these data are plotted on logarithmic paper, the absorptions for immersions longer than 5 seconds fall approximately in a straight line. The average curves for the data from all tests fit the following exponential equations:

Log Lateral Absorption = -0.38 + 0.19 log immersion in seconds

Log End Absorption = 0.64 + 0.18 log immersion in seconds

The second terms of these equations, indicating slope of curve, show that lateral and end absorptions have the same relationship to length of immersion and differ only in the relative amount of absorption, the end absorption being about 10 times the lateral per unit area.

In two tests the combined absorptions of lateral and end surfaces were secured by using uncoated test blocks. The slopes of the curves are flatter (0.11 and 0.14 log immersion time) than for lateral or end absorptions alone (0.16 to 0.25 log immersion time). These flatter curves might be due to differences in the rate of build-up of back pressure or other physical phenomena accompanying simultaneous penetration from both ends and sides. This difference was further shown in one test with matched groups having (1) ends sealed, (2) sides sealed, and (3) no surfaces sealed. The sum of the absorptions through the ends and the sides was considerably greater than through both simultaneously:

Treatment	Absorption, in grams per block
End-coated	17.1
Side-coated	17.9
Uncoated	22.4

It is expected that such effects would decrease as the size of the test block increased and probably would be negligible in full-sized lumber.

In two tests penetrations were also determined for different immersion periods. Because of the small lateral penetration and the difficulty in measuring it accurately, only end penetrations were considered. The following equations were determined for the average exponential curves of the data:

Log End Absorption = 0.58 + 0.22 log immersion in seconds

Log End Penetration = 1.01 + 0.21 log immersion in seconds

Table 14.--Absorptions of pentachlorophenol in mineral spirits and of water, with various immersion periods

Solution	Immersion period								
	5 seconds	10 seconds	30 seconds	1 minute	3 minutes	10 minutes	15 minutes	30 minutes	60 minutes
LATERAL SURFACES									
	Grams per 100 square centimeters								
Pentachlorophenol	1.0	...	...	...	1.2	...	1.6	...	2.0
Do.	.7	...	...	...	1.2	1.4	...	1.8	2.0
Do.	.8	...	...	...	1.3	1.6	...	2.0	2.2
Pentachlorophenol plus water repellent	.6	...	...	...	.8	1.3	...	1.6	1.9
END SURFACES									
	Grams per 100 square centimeters								
Pentachlorophenol	8.2	...	...	...	15.9	...	20.7	...	26.2
Do.	6.0	...	...	...	9.5	13.6	...	16.7	16.9
Do.	5.1	...	...	...	8.7	11.2	...	13.9	15.5
Pentachlorophenol plus water repellent	6.3	...	...	...	12.9	13.5	...	17.8	24.2
LATERAL AND END SURFACES									
	Grams per sample								
Pentachlorophenol	...	4.4	...	...	5.8	6.6	...	7.5	...
Pentachlorophenol plus water repellent	...	...	6.7	8.0	9.3	10.1	...	...	...
Water	...	...	6.7	7.8	9.2	9.7	...	...	...

These data indicate a near linear relationship between rates of absorption and average penetration, at least so long as no disturbing elements such as fungus infections are involved.

Field exposure tests (28) have shown that with 3-minute dips important decay starts to appear in above-ground exposure in 5 years, while with dips of 15 minutes or longer no decay appeared in 14 years' exposure with the better treating solutions. With 3-minute and 15-minute immersions the absorptions are approximately 1/2 and 3/4, respectively, of that occurring with 1 hour's immersion. However, short-period cold-soak treatments give only marginal protection, particularly on lateral surfaces. The safest recommendation for protection against decay remains: use as long immersion periods as are feasible. Effectiveness of water repellents in turning rainwater, however, is not increased by immersions over 3 minutes and possibly not over 15 seconds (30).

Preservative With and Without Moisture Repellent

Hubert (10) states that the addition of moisture-repellent oils and waxes in any appreciable amount tends to retard penetration and absorption. The type of repellent also probably influences the amount of retardation. In Forest Service field tests (28), it was found that the samples absorbed only .53 to .91 as much pentachlorophenol plus a water repellent as they did of the straight preservative.

Comparisons of pentachlorophenol and pentachlorophenol plus a water repellent were secured in several tests (table 15).

The data indicate that the addition of a moisture repellent reduced absorption but the extent of interference was less than previously reported (28), even though the same solutions were used. The difference in penetration was more pronounced than that in absorption. In every case the moisture-repellent solution penetrated less laterally and longitudinally. The differences in absorptions are partly masked by the somewhat higher specific gravity of the water-repellent solutions.

Retreatment of Previously Treated Wood

Information on the effect of previously applied oil-carried preservatives on subsequent oil penetration was secured in three tests.

In one test, kiln-dried samples were immersed for 3 minutes in dyed solutions of pentachlorophenol alone or with water repellents. Three weeks later, after much of the solvent had evaporated, the samples were redipped in the solutions. Because dyed solutions were used throughout, penetrations on retreatment could not be measured.

Table 15.--Absorptions by pine sapwood of pentachlorophenol and of pentachlorophenol plus a water repellent in mineral spirits

Immersion period (minutes)	ABSORPTION PER 100 GRAMS					
	Lateral surfaces		End surfaces		Total absorption	
	Pentachlorophenol	Water repellent	Pentachlorophenol	Water repellent	Pentachlorophenol	Water repellent
	- - - - - - - - - - - - - Grams - - - - - - - - - - - - -					
3	...	...	...	...	3.9	3.3
10	...	...	...	...	4.2	4.2
3	1.3 *	1.1	12.0 *	9.6	...	...
3	1.5	1.4	14.2	12.1	...	...
10	1.7 *	1.4	...	...	...	...
10	1.7 *	1.4	15.1 *	12.9	...	...
30	2.5 *	1.9	20.8	19.7	...	...
5	1.6 *	1.3	13.4 *	10.1	...	...
3	...	...	...	...	2.6 *	2.3
	PENETRATION					
	- - - - - - - - - - - Millimeters - - - - - - - - - - -					
3	3.0 *	2.4	34 *	25	...	...
3	3.1 *	2.3	22	19	...	...
10	1.8	1.7	...	...	...	...
10	4.2 *	2.3	30	25	...	...
30	4.4 *	2.5	45 *	36	...	...
5	4.6 *	2.3	29 *	23	...	...

* Significantly greater at 5-percent level or better.

The second test was similar except that 10-minute immersions were used and the samples to be retreated were originally dipped in undyed solutions. All retreatment was with dyed solutions.

The third test was similar to the second, except that the original treatment was a 3-minute immersion and the retreatment a 10-minute soak, and the interval between treatments was 8 months.

The results of all 3 tests are given in table 16. Wood treated with either pentachlorophenol or pentachlorophenol plus a water repellent resisted subsequent retreatment for a few weeks. Retreatment after 8 months showed that only those samples previously treated with the water-repellent solution were resistant and even with them the degree of resistance was not great.

It would seem that the best treatment would result from getting the best absorptions and penetrations possible on the initial treatment rather than rely on a cheaper initial treatment followed by subsequent retreatments. With brush treatments, it would appear that the complete treatment should be accomplished without drying between coats.

When retreatments seem desirable and painted surfaces are involved, retreatment should be delayed until the paint film is well weathered. Some informal tests indicated that paint films (TT-P-40) remain quite impervious to oil solutions until sufficiently weathered to show the wood grain through the film.

Air Temperatures

As far as wood to be painted is concerned, it is unlikely that oil carriers heavier than kerosene will be used. Also, brush, dip, and short-period soak applications will be made at air temperatures. With light oils there will probably be little change in viscosity with varying weather conditions and little direct effect on absorptions and penetrations. Nevertheless, three tests were designed to determine the direct and possibly indirect effects of prevailing temperatures in the Gulf Coast area.

In the first test, pine sapwood was given 5-second and 3-minute dips in 5 percent pentachlorophenol in kerosene. One group of samples and the treating solution were refrigerated for 2 hours and the other group stored at room temperature (88° F) before dipping. Absorptions were:

Immersion time	Absorptions per sample		
	50-54° F	88° F	Difference
	Grams		
5 seconds	1.95	1.45	0.50 ± 0.34
3 minutes	2.26	1.90	.36 ± .06 **

** Significant at 1-percent level.

Table 16.--Effects of dips and soaks in 5 percent pentachlorophenol and 5 percent pentachlorophenol plus water repellents in mineral spirits on absorptions and penetrations with subsequent dips and soaks

Original and retreating periods and original treating solution	ABSORPTION PER 100 GRAMS					
	Lateral surfaces			End surfaces		
	Original treatment	Retreatment with: Pent.	Retreatment with: Pent. and water repellent	Original treatment	Retreatment with: Pent.	Retreatment with: Pent. and water repellent
	Grams					
3 minutes + 3 minutes						
Pentachlorophenol	1.4	0.5	0.4	11.6	2.5	2.6
Pentachlorophenol plus water repellent	1.1	.5	.4	9.5	1.7	1.5
10 minutes + 10 minutes						
Pentachlorophenol	1.8	.3	.3	14.9	2.3	2.3
Pentachlorophenol plus water repellent	1.5	.3	.3	13.8	1.9	1.7
3 minutes + 10 minutes						
Pentachlorophenol	2.4 1/	2.3 1/	...	...	...	...
Pentachlorophenol plus water repellent	2.1 1/	1.2 1/	...	...	...	...
	PENETRATION					
	Millimeters					
10 minutes + 10 minutes						
Pentachlorophenol	4.2	1.2	1.2	29.6	6.8	6.4
Pentachlorophenol plus water repellent	2.3	.8	.7	24.8	3.8	3.1
3 minutes + 10 minutes						
Pentachlorophenol	8.3	7.6	...	36.0	30.7	...
Pentachlorophenol plus water repellent	2.3	3.9	...	15.0	6.9	...

1/ Total absorptions, grams per sample.

In the refrigerated group the wood probably had a higher temperature than the solution. This would give the effect of a mild hot and cold bath, and would thus increase absorption. With the 5-second dip the sample-to-sample variability was too great for a significant difference between the groups.

Again, one matched group of pine sapwood samples was dipped for 3 minutes in 5 percent pentachlorophenol in kerosene during December, when the air temperature was 48° F. The other group was dipped in May, when the air temperature was 77° F. On both occasions samples were dipped after 3 or 4 days of fairly constant temperatures. Absorptions were:

At 48° F.	4.28 grams
At 77° F.	4.11 grams
Difference	0.17 ± 0.13 (not significant)

Finally, one set of pine sapwood samples was wrapped in moisture-proof paper and refrigerated at 40° F, along with sufficient dipping solution (5 percent pentachlorophenol in kerosene), for 30 days. The other set was stored in the laboratory. Both were dipped during warm weather (77° F). The absorptions (per 100 square centimeters) secured were with 3-minute dips:

Absorbing surface	77° F	40° F	Difference 1/
	- - - - - - - - - - - - Grams	- - - - - - - - - - -	
Lateral	1.43	1.29	0.14 ± .12
End	13.80	13.49	.31 ± 1.15

1/ Not significant in either case.

The tests bear out the contention that the normal treating temperatures likely to be encountered in the South will have little effect on treatment through changes in viscosity of treating solutions in which kerosene and mineral spirits are used as carriers. However, the tests indicate that the lower heat conductivity of the wood as compared to the treating solution can appreciably affect absorption when temperatures fluctuate. With a falling temperature, the temperature of the wood may be higher than that of the solution, resulting in a mild hot-and-cold bath effect and resultant increased absorptions. With a rising temperature, the effect would presumably be reversed.

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